ATHYS: a hydrological environment for spatial modelling and coupling with GIS

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Abstract ATHYS was born out of the need to define and develop an operational tool for using spatially distributed hydrological models. These models require processing of a large volume of hydrological and geographical data and the use of specific tools and complex software (DBMS, image processing, GIS). For hydrologists, these tools are not always easy to manage. Contrary to the solution by integrating models in GIS, ATHYS offers an environment designed more specifically for hydrologists. This environment regroups in a homogeneous framework three main modules: (a) a preprocessor for hydrological data, which reads, displays, selects and stores discharge and rainfall time series data; (b) a preprocessor for geographical data, which includes a viewer for map files and a DEM processing tool; (c) a list of distributed models which can be used and compared according to the user’s choice. ATHYS’S interface is based on Tcl/Tk, which was developed in a UNIX/X-Windows environment. An application of ATHYS is also presented, showing the importance of such tool in hydrological modelling.

INTRODUCTION

The use of spatial hydrological models is often not easy. It implies the processing of hydrological and rainfall data, manipulation of geographical information and DEM data, programming of algorithms and display modules. The latter have to be adapted to a distributed parameter structure. Most of these tools exist as separate modules which are not necessarily adapted to the needs of the hydrologist. GISs are essential for processing spatial information, several of which have been adapted to include a hydrological dimension (Chairat & Delleur, 1993; Delclaux & Boyer, 1993; Romanowicz et al., 1993; Stuart & Stocks, 1993). Their use implies an important investment for hydrologists even though they only use a limited number of functions. On the other hand, hydrologists require specific processing, such as data generation derived from DEM, spatial interpolation of rainfall, etc. These exist in various environments.

Also hydrological models themselves use different systems and are difficult to compare. Thus in order for a hydrologists to model distributed hydrological processes, one must be competent in geography, satellite imaging, geomorphology, geostatistics, algorithmic programming and data processing.

Since ORSTOM collaborates with many developing countries, it was necessary to develop an open system in order to enable cooperation with its partners while remaining compatibility with existing data.
When developing ATHYS (ATelier HYdrologique Spatialisé), our objective was to minimize the external knowledge required by a hydrologist and propose an open, user-friendly environment specific to hydrology. Such system would allow the user to focus on the modelling itself.

STRUCTURE OF ATHYS

Basic principles

The basic principles which preceded the development of ATHYS are:
(a) a dedicated hydrological environment for distributed modelling, including a series of models, DEM processing, hydrological and rainfall data and geographical display, spatial data interpolation;
(b) an application environment completely separated from GIS, image processing and databases. The bridge between these tools is performed using standard file formats (e.g. TIFF, DXF, etc.);
(c) a modular environment which permits integration of external applications and future developments;
(d) work station environment under UNIX/X-Windows with a Tcl/Tk as the user interface language and the Xf program generator (Delmas, 1993; Ousterhout, 1993).

ATHYS is composed of three principal modules (Figs 1 to 3): a preprocessor of hydrological data, a preprocessor of geographical data and the models.

Hydrological preprocessor

This module permits the fusion of stream flow and rainfall data for a water basin including the selection of events for modelling. It also allows display and modification of the selected data.

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**Fig. 1 Functional scheme of ATHYS environment.**
A second module generates a spatial rainfall grid using specific data and interpolation using spline functions or kriging (Delclaux & Thauvin, 1991).

**Geographical preprocessor**

A visual display of cartographic data, VICAIR (VISualisation de CArtes et d'Information Raster) displays spatial information required by the models: raster, vector and point. VICAIR was adapted from the visual display module of a public domain program.
Fig. 3 Example viewers of ATHYS.
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GRASS/TclTk developed by a Canadian company LAS. Integrated with a layer manager, this module permits the superposition of maps and verifies their coherence. Even though the internal data structure is compatible with GRASS, VICAIR permits access to other data formats such as TIFF, ASCII, etc.

The second module is a DEM which was developed by Depraetère (1991) and contains the following modules: calculation and correction of drainage basins, generation of slope maps and derived files (convexity, horizontal and vertical, etc.).

Hydrological models

Three models are integrated or currently being integrated into ATHYS.

(a) MERCEDES, developed by Bouvier (1994) and Bouvier et al. (1994), is a conceptual spatial model based on square grids adapted to surface runoff. It includes four production parameters, simulation of groundwater (levels and drainage flux) and two continuous losses (subtractive and/or multiplicative). The contribution of each grid to the stream flow at the discharge is considered using two parameters which establish propagation speed and a third parameter which determines the behaviour of the crest wave. The main advantages of MERCEDES are that it is simple and easy to use and can be applied to a large range of water basins: urban basins of only a few hectares up to tens of square kilometres, natural mountainous water basins of 30 to 100 km², large basins with thousands of square kilometres. We will present an application of this model, using a complete example which simulates overland runoff in an urban area, using several layers of drainage.

(b) MODLAC, developed by Girard (1982), is a distributed conceptual model adapted to rural water basins with or without retention equipment. It permits the modelling of the basin’s behaviour or the simulation of land use or development scenarios. It functions on a scale of 1-day time steps for water basins greater than 100 km². The surface layer is divided into square grids of varying sizes depending upon the amount of spatial data. The model integrates thirteen production functions determined by the availability of diverse data which divides flow into surface runoff, infiltration, groundwater storage and evapotranspiration. The discharge is calculated by taking into account the length and time required for the water to pass through a grid to the outflow point of the basin.

(c) MODCOU was developed using the same principal as MODLAC: same spatial land division, same scale, production function and transfer per layer. In addition, MODCOU contains a subsurface model with functions for the transfer in nonsaturated area, simulation of subsurface drainage between aquifers using Darcy’s law, and a function for the flux exchange between the aquifers and rivers.

AN APPLICATION OF ATHYS: CHARACTERISTICS OF FLOOD RISK IN AN URBAN AREA

The risk of flooding due to runoff is a major concern in urban areas because of impermeable surface and inadequate drainage. These factors can lead to violent flooding in a short time within a limited region.
Even though this phenomenon is a real problem, the tools required to predict and simulate the risk of flooding are still relatively crude. The development of GIS provides a means to objectively describe and quantify these risks. We provide an example using the program ATHYS in combination with a distributed hydrological model, MERCEDES and a fine spatial distribution in an urban area.

Method

In our approach, the characterization of flood risk requires three distinct steps:
(a) determine all the potential tributaries within the basin;
(b) compare all the tributaries to drainage capacity;
(c) in the case of saturation calculate flooding of urban areas.

We wish to simulate all areas of flux within the basin, including the points with inadequate drainage. This is the advantage of our method.

When considering and calculating runoff, drainage in urban area can be artificially modified in relation to natural topography. The different channels, collectors, pipes and streets can considerably modify drainage in relation to natural slope. It is this combination of natural and artificial drainage which our method simulates. If drainage capacity is sufficient, drainage follows the imposed path. If flooding occurs, the excess water drains according to the natural topography. In our example, runoff is calculated using the MERCEDES model which uses functions with two layers of drainage.

We have applied this method to a pilot zone in Ouagadougou (Burkina Faso). This urban area is particularly good as it represents many of the possible flux conditions. This zone covers 610 ha, for which a grid of 10 × 10 m² is used. This scale provides all the necessary geographical information.

Fig. 4 Urbanization of the Ouagadougou pilot zone.
Required data

(a) *Land use maps.* The digitization of parcels permits the differentiation of potential runoff. The image in Fig. 4 (originally from a GIS) was recovered by ATHYS in a raster format, then converted and formatted by the data exchange module.

(b) *Slopes and drainage directions.* This data is provided by ATHYS via a function associated with a DEM. The module performs interpolation of the barycentre or by spline functions, extraction of the slope and direction of natural drainage with corrections and consideration for the urban drainage system (Fig. 5).

(c) *Level of drainage.* This information, which is difficult to obtain, is defined with default values for all the different drainage "objects", 1 m$^3$ s$^{-1}$ for streets, 20 m$^3$ s$^{-1}$ for different collectors in accordance with their known dimensions.

![Fig. 5 Correction of the drainage topographic model in relation to the network.](image)

![Fig. 6 Distributed peak flows in the urbanized areas of the Ouagadougou pilot zone.](image)
Simulation results

The model MERCEDES was applied to the pilot zone and a 50 year flood was simulated. Figure 6 illustrates:

- Areas where flux occurs within the zone. This includes all the points within the basin, including collectors and streets. These areas are represented as maximum possible runoff which can pass through a grid.
- The same areas, limited by the different areas which are outside the urban zone. The values for the maximum flow have been averaged for clearer visual display and superimposed upon the land use maps in order to provide a better representation of risk flooding areas and flooding extent.

Other results are also accessible. Critical points within the drainage network, the classification and surface area of different urban classes, their drainage potential and exposure to flooding, for example \( x \text{ m}^3 \text{s}^{-1} \) every \( N \) years, etc.

Limitations of the method

Even though the perspectives of this method are promising, one must consider that its validity depends upon certain conditions, most of which are satisfied, e.g. validation of hydrological operations, data transfer, communication between the different drainage levels, etc. The program opens many perspectives concerning calculations and representing results. As further in-depth analysis is necessary to validate this method, it is necessary to remain prudent when considering the results obtained.

CONCLUSION

The objective of the ATHYS project is to make available an operational hydrological modelling environment. The starting point of this project was to define an open framework between specialized complex software and simple hydrological computational programs. The most suitable computer tools were chosen, the existing applications were gathered and two models, MERCEDES and MODLAC/MODCOU, were updated. This open structure allows an easy integration of new tools and models.

Concerning the next development, a second part, which is presently being analysed, will be undertaken. It will be based on the development of a "personal" distributed model. In this model, the user will be able to choose from a database of hydrological predefined objects the components and modules, which are consistent with the processes he wants to study. Examples of components and modules are loss and transfer functions, physical laws and optimization procedures.

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